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IS 5469-3 (1973): Code of practice for the use of semiconductor junction devices, Part 3: Thyristors [LITD 5: Semiconductor and Other Electronic Components and Devices]



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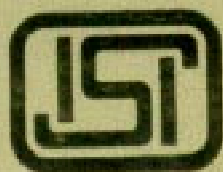
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IS : 5469 (Part III) - 1973

Indian Standard
CODE OF PRACTICE FOR
THE USE OF SEMICONDUCTOR
JUNCTION DEVICES
PART III THYRISTORS

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Indian Standard
**CODE OF PRACTICE FOR
THE USE OF SEMICONDUCTOR
JUNCTION DEVICES
PART III THYRISTORS**

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Indian Standard
**CODE OF PRACTICE FOR
THE USE OF SEMICONDUCTOR
JUNCTION DEVICES**

PART III THYRISTORS

0. F O R E W O R D

0.1 This Indian Standard (Part III) was adopted by the Indian Standards Institution on 15 June 1973, after the draft finalized by the Semiconductor Devices and Integrated Circuits Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard (Part III) covers particular considerations applicable to semiconductor thyristors.

0.2.1 This standard should be used in conjunction with IS:5469 (Part I)-1969* which is a necessary adjunct to this standard and which covers general and common requirements applicable to all thyristors.

0.3 Assistance has been derived from the following while preparing this standard:

BS Doc: 71/20573 Code of practice on the use of semiconductor devices, Part 2 Particular considerations. British Standards Institution.

The use of semiconductor devices. Electronic Valve and Semiconductor Manufacturers' Association, UK.

0.4 This standard is one of a series of Indian Standards relating to semiconductor devices and integrated circuits. A list of standards so far formulated in this series is given on page 19.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS:2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Code of practice for the use of semiconductor junction devices: Part I Application to all devices.

†Rules for rounding off numerical values (revised).

1. SCOPE

1.1 This standard (Part III) is intended to give guidance to all concerned with the design, construction, use and maintenance of equipments using thyristors so that optimum device performance and life may be ensured.

1.1.1 This standard should be used in conjunction with IS:5469 (Part I)-1969* which is necessary adjunct to this standard.

2. GENERAL

2.0 In this standard certain special considerations that apply to the use of thyristors are described and should be read in conjunction with IS:5469 (Part I)-1969*.

2.1 The term 'thyristor' as used here covers reverse blocking triode thyristors, reverse conducting triode thyristors and bi-directional triode thyristors (triacs). Some of these types may be available with 'turn-off' characteristics and Fig. 1 illustrates diagrammatically the characteristics of the different varieties. Thyristors are further classified according to whether the

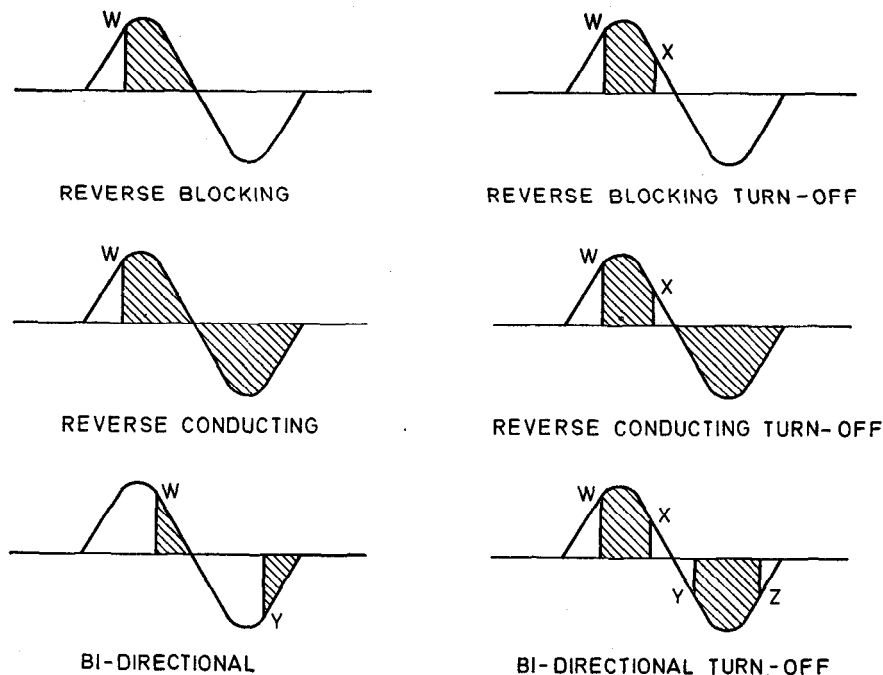


FIG. 1 TYPES OF TURN-OFF CHARACTERISTICS OF THYRISTORS

*Code of practice for the use of semiconductor junction devices: Part I Application to all devices.

triggering signal is applied between gate and cathode or gate and anode. These are referred to as 'cathode-triggered' and 'anode-triggered' respectively.

2.2 The subsequent clauses deal in detail with the reverse blocking, non-turn-off cathode-triggered thyristor, followed by details of the principal difference between this basic type and the bidirectional triode thyristor.

3. CHARACTERISTICS AND RATINGS

3.1 **Reverse Characteristics** — The behaviour with reverse voltage applied is similar to that of a power diode except that the anode current may be considerably increased if forward gate current is flowing (*see Fig. 2*). If this condition is permitted by the ratings, allowance may have to be made for increased dissipation.

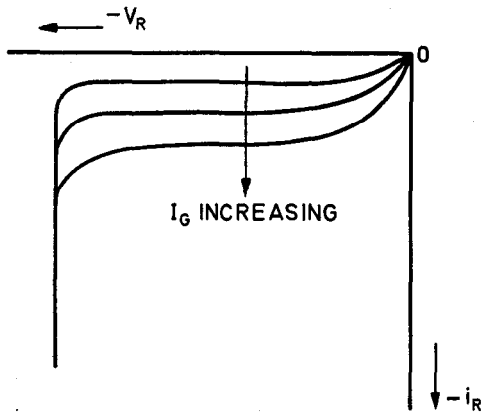


FIG. 2 EFFECT OF FORWARD GATE CURRENT ON REVERSE CHARACTERISTICS OF REVERSE BLOCKING THYRISTORS

3.2 **Reverse Rating** — Reverse ratings are similar to those of power diodes except that the application of reverse voltage may be forbidden when forward gate current is flowing.

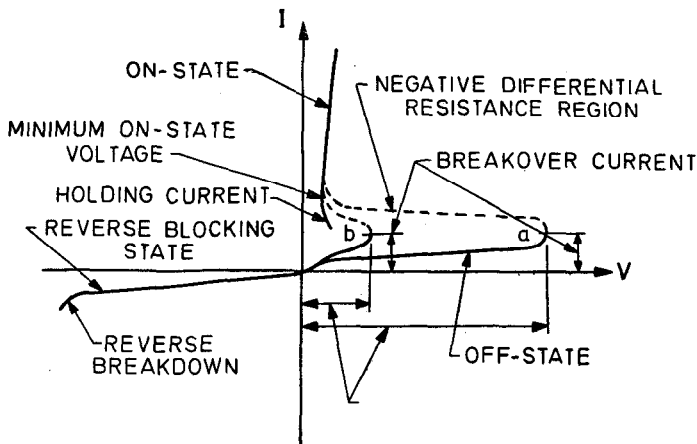
3.3 Forward Characteristics

3.3.1 The basic forward characteristic illustrated in Fig. 3, comprises two parts. The first part represents the off-state, which exists as long as the thyristor has not been triggered by gate current or other influence; in this state only a small leakage current flows with any applied voltage below a critical value which is termed the breakover voltage, V_{BO} .

3.3.2 The breakover voltage is a complex function of the rate of change of applied voltage, the temperature and the immediately preceding electrical conditions of the device.

3.3.3 A pulse of gate current or an applied voltage in excess of V_{BO} may trigger the thyristor into the on-state, represented by the second part of the characteristics which resembles the forward characteristic of the diode, albeit with a somewhat higher voltage drop.

3.3.4 In normal usage, the highest applied voltage in the forward direction is kept below the minimum breakover voltage and the thyristor is put into the on-state by a gate current when required.



NOTE — Curve *a* corresponds to zero gate current and curve *b* is with gate current present.

FIG. 3 VOLTAGE CURRENT CHARACTERISTICS FOR REVERSE BLOCKING TRIODE THYRISTORS

3.3.5 At normal operating currents the instantaneous voltage drop decreases with increasing junction temperature at the rate of about 2 mV/deg C. At very high currents, that is, towards the maximum surge current rating, the variation with temperature diminishes and may even reverse in sign.

3.3.6 There are two gate circuit conditions either of which will ensure that a device of a given type will go into the on-state with given principal circuit conditions and device temperature:

- a) the gate current shall exceed I_{GT} for a sufficient time, or
- b) the gate voltage shall exceed V_{GT} for a sufficient time.

3.3.7 Either I_{GT} or V_{GT} or both may be specified for a given type of device. The values given normally refer to indefinitely long times of application. For shorter times, greater values will apply.

3.3.8 There are two gate circuit conditions, both of which shall be complied with to ensure that no device of a given type will go into the on-state with given principal circuit conditions and device temperature:

- a) the gate current shall be less than I_{GD} , and
- b) the gate voltage shall be less than V_{GD} .

3.3.9 Where the manufacturer specifies only one of these conditions, this may be taken to imply that the other is satisfied.

3.3.10 There are two critical values of the principal current which determine whether or not a device will go into self-sustained conduction (latch):

- a) Latching current, I_L , and
- b) Non-latching current, I_{NL} .

To ensure latching, the circuit should be so designed that a principal current at least equal to I_L flows within the duration of the gate triggering pulse. It may be observed, increasing the gate current may increase the latching current. The full current-carrying capability of the device is not established immediately on triggering and this leads to a limitation on the rate of rise of principal current (di/dt) [see 3.4.2 (f)] in the on-state.

3.3.11 There are two critical values of the principal current which determine whether or not a device will remain in self-sustained conduction (hold):

- a) Holding current, I_H , and
- b) Non-holding current, I_{NH} .

To ensure the operation of the thyristor in the on-state, the principal current should never be allowed to fall below the holding current I_H .

3.4 Forward Ratings

3.4.1 Off-State — The ratings in this condition (which are similar to the reverse ratings of a power diode) are as follows:

- a) Repetitive peak off-state voltage, V_{DRM} .
- b) Non-repetitive peak off-state voltage, V_{DRM} .
- c) Continuous (direct) off-state voltage, V_D .

- d) dv/dt maximum, which may be strongly dependant on circuit conditions.

NOTE — The use of the so-called 'crest (peak) off-state voltage, V_{DWM} ' based on an arbitrarily assumed ratio of surge voltage to nominal crest operating voltage, is strongly deprecated.

3.4.1.1 Observance of these ratings will ensure that breakover, in the absence of a gate signal, does not occur under any circumstances.

3.4.1.2 For the ratings applicable immediately after the cessation of forward conduction, reference should be made to 3.9.

3.4.2 On-State — The current ratings in this condition which are similar to the forward current ratings of a power diode are as follows:

- a) On-state current (whole cycle average), $I_T(AV)$ (on the assumption of half-sinoidal waveform) (see 3.4.3).
- b) On-state current (whole cycle average), at 'X' degrees conduction angle, $I_{T(X)}$ (on the assumption of rectangular waveform) (see 3.4.3).
- c) Continuous (direct) on-state current, I_T (see 3.4.3).
- d) Repetitive peak on-state current, I_{TRM} .
- e) Non-repetitive peak on-state current, I_{TSM} .
- f) di/dt maximum, which may be strongly dependent on gate and principal circuit conditions.

Deterioration of the thyristor caused by repeatedly exceeding the di/dt rating is often slow and the absence of immediate catastrophic failure is therefore no proof that the operating conditions are satisfactory in this respect.

3.4.3 Interpretation of On-State Ratings

3.4.3.1 Current ratings cannot be computed solely on the basis of total dissipation, steady-state thermal resistance and permitted junction temperature, because allowance has to be made for factors, such as the rms current-carrying capacity of the connections, the permitted internal temperature gradient and cyclic variations in junction temperature. Because of this, and because the dissipation itself depends on a number of factors, mean current ratings published for sinusoidal or rectangular waveforms should not be taken to apply accurately to other waveforms nor should they be used as the basis of calculation of ratings for other waveforms.

Duty cycle current ratings — Current ratings for fluctuating loads are normally calculated from the manufacturers dissipation characteristics and the transient thermal impedance data, the junction temperature being kept within the maximum rated value thus retaining gate control.

3.4.3.2 A special case arises in power packs for electronic equipment using a reservoir capacitor. It is usual to limit the peak value of the charging current to this capacitor by the inclusion of an appropriate value of resistor in the circuit. Manufacturer's data shall specify either the value of this resistor or the value of the non-repetitive peak on state current, I_{TSM} .

Surge current ratings — At the higher levels of current that may be experienced under fault conditions, the thyristor may lose control and fail to block forward voltage even though the surge current rating (I_{TSM}) has not been exceeded.

3.5 Gate Ratings — There are five principal gate ratings which shall be observed as follows:

- a) Maximum peak forward gate voltage, V_{FGM} .
- b) Maximum peak reverse gate voltage, V_{RGM} .
- c) Maximum peak forward gate current, I_{FGM} .
- d) Average gate power, $P_{G(AV)}$.
- e) Peak gate power, P_{GM} .

These are applicable between t_{case} (Max) and t_{case} (Min).

3.6 Switching Characteristics and Triggering Current

3.6.1 The switching-on of a thyristor under the influence of a gate current pulse occupies a period of time which can conveniently be regarded as being comprised of a delay time followed by the time taken for the forward voltage to fall (fall time) as illustrated in Fig. 4. The delay time (and to a lesser extent, the fall time) decreases with increasing amplitude and decreasing rise time of gate current. During the fall time, the instantaneous product of voltage and current will pass through a high value which will be greatest with capacitive and least with inductive loads. As this occurs at each switching-on operation the mean dissipation increases with frequency of switching and current derating may be necessary at high frequencies; manufacturers normally supply information on this derating. Dissipation during switch-on may be reduced and di/dt conditions improved by connecting an inductor in the principal circuit in order to slow down the initial rise of current.

3.6.2 To ensure a short delay time with a 'worst case' thyristor, an over-drive ratio (actual firing current to I_{GT}) of 1.4 at the lowest operating temperature is a reasonable practical minimum.

3.6.3 For the reduction of switching losses or the improvement of di/dt rating the gate current should frequently be much greater than I_{GT} and its rise-time kept short. To obtain the very short rise time required to yield

the best possible di/dt ratings, a fairly high voltage source of gate current may be recommended by the manufacturer to allow for the finite response time of the gate junction. An acceptable gate current waveform that minimizes the mean gate dissipation and the demands upon the pulse-generator is shown in Fig. 5, wherein the decay time-constant of the initial high-amplitude pulse may be of the order of $10/\mu s$ (see also 3.8 and 4.3).

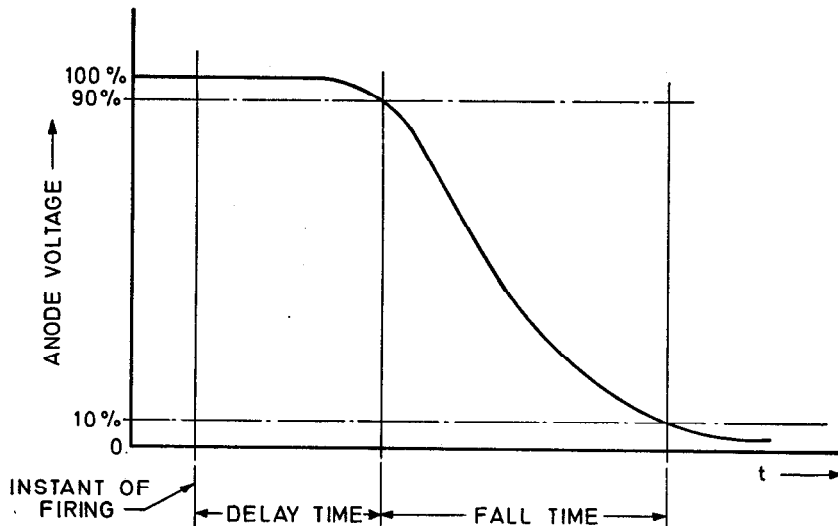


FIG. 4 VARIATION OF THYRISTOR ANODE VOLTAGE ON FIRING BY GATE CURRENT

3.6.4 Long gate pulses are sometimes desirable (see 3.3).

3.6.5 In all cases, care should be taken not to exceed the gate ratings but with very fast rising pulses the initial gate impedance may be significantly greater than that indicated by the static characteristics and this may have to be taken into account in estimating the maximum peak forward gate voltage, V_{RGM} (see 3.5).

3.7 Use of Fast-switching Thyristors — In applications where the power dissipated in the thyristor during the switching-on operation is especially significant, because of very severe switching conditions or a high repetition frequency, or both, it may be advantageous to use one of a variety of special types of thyristor designed to exhibit an exceptionally rapid fall, to a low level, of anode-to-cathode voltage when fired. Most such thyristors embody an auxiliary structure within the semiconductor element in order

to produce an augmented triggering current largely independent of the externally applied firing signal, and the short fall time is not necessarily accompanied by a correspondingly short delay time. Special gate triggering requirements may be specified by individual manufacturers.

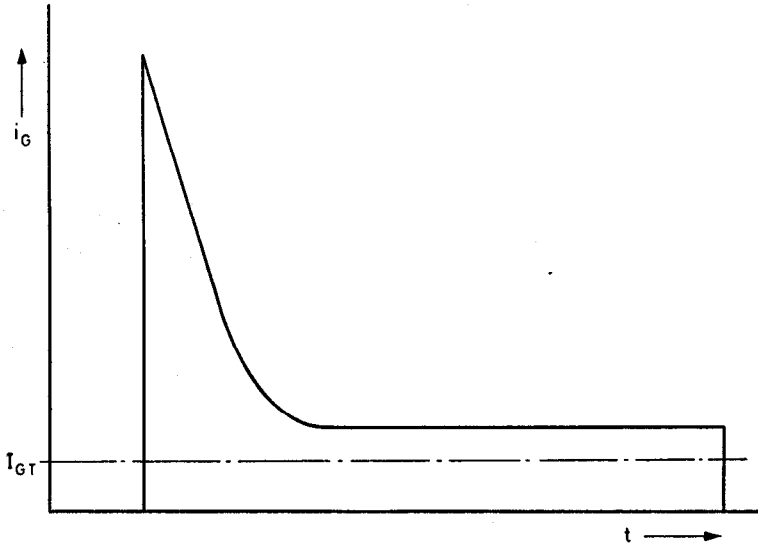


FIG. 5 ACCEPTABLE WAVEFORM OF GATE CURRENT PULSE
WITH HIGH-AMPLITUDE LEADING EDGE

3.8 Effects of Reverse Gate Voltage

3.8.1 Reverse gate voltage may be applied during non-conducting periods up to the limit of the gate voltage rating to assist in the suppression of stray pick-up; it may in some circumstances also improve the thyristor characteristics but it should not be assumed that it will bring about any appreciable benefit in this respect except on the basis of information supplied by the manufacturer.

3.8.2 It is undesirable to employ a gate pulse, that is, followed by an appreciable reverse overshoot as this may effect both the latching value and the holding value of the principal current.

3.9 Recovery Characteristics

3.9.1 The reverse recovery time, t_{rr} (see Fig. 6) is the time taken by the thyristor to regain its full reverse-blocking capability after the instant when

the forward principal current reaches and passes through zero. Both t_{rr} , and the carrier-stored charge, idt , represented by the reverse recovery current, i_r that flows (circuit permitting) during this period, tend to be greater with high forward current and with high rate of change of current at the end of forward condition. t_{rr} may be considerably increased if the reverse voltage across the thyristor is not allowed to rise appreciably, as for example when a diode is connected in inverse parallel with the thyristor or when the thyristor is turned off by short-circuiting it, t_{rr} may similarly be increased if no appreciable reverse recovery current is allowed to flow, as for example when the thyristor is turned off by open-circuiting it.

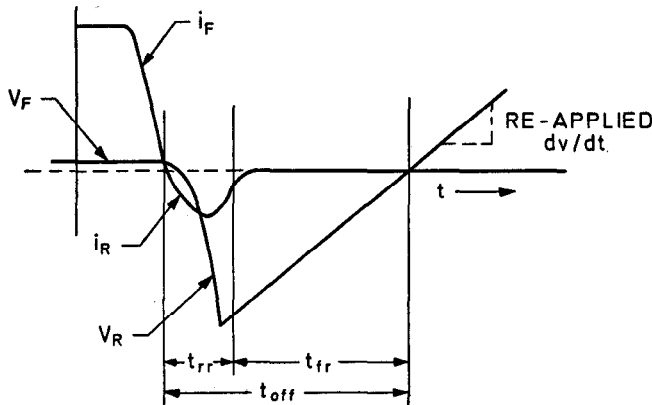


FIG. 6 TYPICAL VOLTAGE AND CURRENT WAVEFORMS DURING FORCED COMMUTATION

3.9.2 If the circuit conditions are such that the reverse voltage rises significantly before the reverse recovery current falls to zero, there is a certain energy loss associated with the change from forward conduction to reverse blocking at high repetition rates, this may constitute a significant part of the total dissipation in the thyristor.

3.9.3 The forward recovery time, t_{fr} , is the further time taken by the thyristor to regain its full forward-blocking capability after it has completed its reverse recovery (forward recovery cannot begin until reverse recovery is substantially complete).

3.9.4 t_{fr} increases very significantly with junction temperature, and slightly with re-applied dv/dt .

3.9.5 The 'turn-off' time normally measured and quoted by device manufacturers is the sum of t_{rr} and t_{fr} under specified conditions.

3.9.6 It is usually desirable in circuit design to allow a generous safety factor on thyristor turn-off times.

3.9.7 Forced-commutation, or in some cases the use of resonant circuits, provides the means of turning off conducting thyristors in circuits which operate from dc supplies and therefore lack the facility for natural current decay or natural commutation afforded by the varying supply voltage in ac supplied circuits.

4. APPLICATIONS OF THYRISTORS

4.1 Safety to Personnel — Owing to the existence of leakage current and the possibility, however remote, of breakdown or spurious operation, the thyristors do not offer high impedance. Hence they shall not be relied upon as isolators where safety of personnel is involved.

4.2 Modes of Operation — A thyristor may turn off in operation as a result of:

- a) the natural decay of the on-state current to below the holding current value,
- b) natural commutation, in which the on-state current is diverted into an alternative path for a period which is longer in comparison with its turn-off time, or
- c) forced commutation, in which the thyristor is caused to pass briefly into a reverse blocking state by the deliberate application of a reverse voltage before off-state voltage is re-applied.

4.3 Gate-Pulse Duration

4.3.1 There is a minimum time period over which a gate pulse shall persist, if the on-state is to be achieved. In the event of an appreciable delay in the growth of the principal current to the latching value or in the presence of oscillations therein, it will be necessary to use a long gate pulse in order to prevent the thyristor from reversing prematurely to the off state.

4.3.2 In many applications the duration of the gate pulse is subject to a lower as well as an upper limit set by basic considerations of circuit operation (a repeated short pulse in some cases serving the same purpose as one long pulse), as in a bridge converter with thyristors in all its arms.

5. SUPPRESSION

5.1 Transient Voltage Suppression

5.1.1 Transient overvoltages may arise from the same origins as discussed in 3.2.2 of IS:5469 (Part II)-1973* with reference to diodes and as a result

*Code of practice for the use of semiconductor junction devices: Part II Diodes.

of the switching of the thyristors themselves. These transient voltages can be reduced by resistor-capacitor circuits, nonlinear resistors, or selenium surge suppressors.

5.1.2 Where thyristors, or thyristors and diodes, are connected in inverse parallel, as in an ac regulator, anode breakover, even when permissible, should not be relied upon as a voltage limiting mechanism. This is primarily because the manufacturers do not normally specify the maximum V_{BO} which may, therefore, be in excess of the reverse voltage rating of the inverse parallel connected device.

5.2 di/dt and Reverse Current Limitation — In some circuit configurations, the reverse recovery current of one thyristor forms part of the forward current of another thyristor which is just commencing conduction. This reverse recovery current therefore affects the initial ' di/dt ' of the second thyristor. Similarly the firing of a thyristor may give rise to a big reverse recovery current in an associated diode, as in a controlled rectifier equipment with a free-wheeling diode. In such cases the suppression measures as used for transient voltage suppression will solve both problems. Resistance may in some cases improve matters by reducing the peak current and absorbing some energy but will not limit the initial rate of rise of current and in most cases it is desirable to use inductors.

5.3 Suppression of Rate of Change of Principal Voltage (dv/dt) — In operation a thyristor shall be subjected to voltages (between its principal terminals) which may undergo rapid changes. Such rapid changes can result in spurious breakover and in high transient reverse currents and preventive measures may therefore be needed. In principal, such measures take the form of a capacitor connected to the principal terminals of the thyristor and in addition it may be found necessary to use a resistor for damping and/or a diode in series with the capacitor to prevent discharge through the thyristor taking place at an excessive rate.

5.4 Undesirable Effects of Suppression Circuits

5.4.1 As noted above, an RC suppression network may present a problem because of the resulting discharge current through the thyristor; in fact such a network, whether provided for dv/dt or for transient overvoltage suppression, may constitute the main source of high di/dt , as for example in the case of a network connected at the input of a thyristor in which the di/dt at commutation would otherwise be limited to a very low value by supply inductance; nonlinear surge suppressors do not give rise to this problem.

5.4.2 Equally, inductance connected in series with a thyristor or diode to limit di/dt or reverse current may cause transient overvoltages through carrier storage effects (similarly with inductors used for current-sharing). Suppressor networks shall therefore be designed with due regard to all their effects and interactions.

6. SERIES OPERATION

6.1 Voltage-sharing between series-connected thyristors is basically secured as with diodes, by parallel resistors for steady-state conditions and by capacitor (with series resistors for damping and current-limiting) for externally applied transient voltages, but additional difficulties are introduced by the higher rate of rise of reverse voltage during commutation (this may apply equally to diodes used in association with thyristors) which tends to cause transient mis-sharing because of differences in reverse recovery time, and differences in turn-on time, which tend to cause transient mis-sharing of forward blocking voltage. In difficult cases (for example, at high frequency, where large sharing capacitors are an embarrassment) devices can be matched for reverse recovery or turn-on time, though preferably not both. Forward voltage sharing can be greatly assisted by employing high-amplitude gate current pulses with short rise-time, applied simultaneously to all the thyristors, which also increase the thyristors' ability to withstand the effects of large sharing capacitors.

6.2 It will be appreciated that the series R-C circuit in parallel with the thyristors serves simultaneously:

- a) to limit dv/dt .
- b) to promote transient reverse and off-state voltage sharing.
- c) to reduce the effect of differences in the recovery time and turn-off time of individual devices.
- d) to swamp the mis-sharing effect of stray capacitance.

6.3 The size of capacitor chosen shall depend on the most onerous of these functions.

6.4 The need for series operation can often with advantage be avoided by using double-way circuits of the series connection of complete rectifier circuits.

7. PARALLEL OPERATION

7.1 The variation in forward conduction characteristics tends to be greater in thyristors than in diodes and it may not be practicable to achieve adequate current sharing by device matching alone; it is sometimes the practice in parallel operation to employ current sharing reactors (which may also be suitable for di/dt limitation) in conjunction with selection of devices by the manufacturer. The use of sharing reactors also ensures that no difficulty is encountered in establishing conduction in parallel operated thyristors which may have different turn-on times. There is frequently

same choice as to the location of current-sharing impedance in relation to a rectifier (or synchronous converter) circuit, as between, for example the ac lines, the arms of the rectifier assembly and the dc output circuit.

7.2 This choice has normally to be resolved according to individual circumstances having regard to such factors as the other effects of the impedances (for example, fault current limitation), the possibility of high di/dt from alternative sources (for example, the ac and dc sides of a converter) and the requirements of standardization.

7.3 A fault in the firing circuit associated with one or more thyristors in a parallel-connected group will result in excessive loading of the operative thyristor unless a means is provided of proving conduction. The latter is therefore recommended for highly reliable equipment.

8. PROTECTION

8.1 The recommendations given for power diodes are equally applicable to thyristors in rectifier circuits. The following additional considerations may also apply to thyristor equipment, depending on its nature.

8.2 Automatic Current Limiting — Thyristor equipment of all kinds can in general be designed to limit the load current to a safe level (or to function as an overload trip) by phase control or by forced-commutation; it is thus usually possible to guard against overloads and some kinds of fault without recourse to a circuit-breaker, except in so far as the latter may be required to provide back-up protection. The functioning of such protective circuits requires that the specified thyristor junction temperature is not exceeded when forward blocking is required (*see also 3.4*).

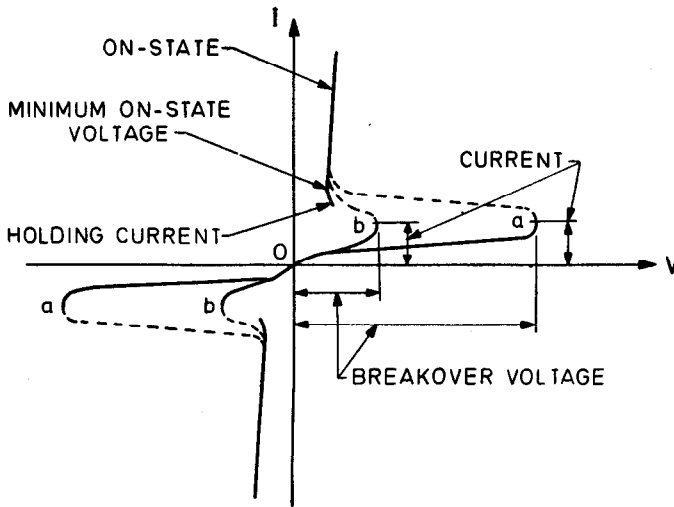
8.3 Loss of Commutation — In inverters and other circuits where operation depends on the maintenance of the correct conditions for commutation, overloads as well as control circuit faults may cause loss of commutation and hence a high-level fault current in the dc circuit against which adequate protection should be provided (*see 8.4*); but some relaxation of surge ratings may be obtainable from the thyristor manufacturer by virtue of the absence of reapplied reverse voltage following the fault.

8.4 Fuses in dc Circuits — When considering the use of fuses for fault clearance in dc circuits, the fuse manufacturer should be consulted regarding their operation under these conditions.

9. BIDIRECTIONAL TRIODE THYRISTORS (TRIACS)

9.1 These have a nominally symmetrical characteristic similar to the forward characteristic of the reverse blocking thyristor for either direction of applied voltage as illustrated in Fig. 7. Provisions of 3.3, 3.4 and 3.6 shall apply equally to bidirectional thyristors, although because the device is used

mainly in ac regulators or switches, the current ratings may be given only in terms which are applicable to this duty and commonly in terms of rms current.



NOTE — Curve *a* corresponds to zero gate current or to a diode thyristor, and curve *b* is with gate current present.

FIG. 7 VOLTAGE CURRENT CHARACTERISTICS FOR BIDIRECTIONAL
DIODE AND TRIODE THYRISTORS

9.2 The majority of bidirectional thyristors can be triggered by a gate current of either polarity with either direction of principal circuit voltage, although other types are obtainable. The sensitivity of a particular thyristor to gate current shall not necessarily be the same for all combinations of gate and principal circuit polarity. The gate ratings correspond to the forward gate ratings of a reverse blocking thyristor as referred to in 3.5.

9.3 The turn-off characteristics of bidirectional thyristors are normally significant only in relation to natural current decay (see 4.2), since the lack of a reverse blocking characteristic raises basic problems in regard to commutation. The ability of the device to withstand a high rate of rise of voltage without breaking over is much reduced by immediately preceding on-state conduction, a situation which commonly arises, as in the ac regulator with an inductive load, is illustrated in Fig. 8 which shows at (b) the current in the thyristor and at (c) the voltage across it.

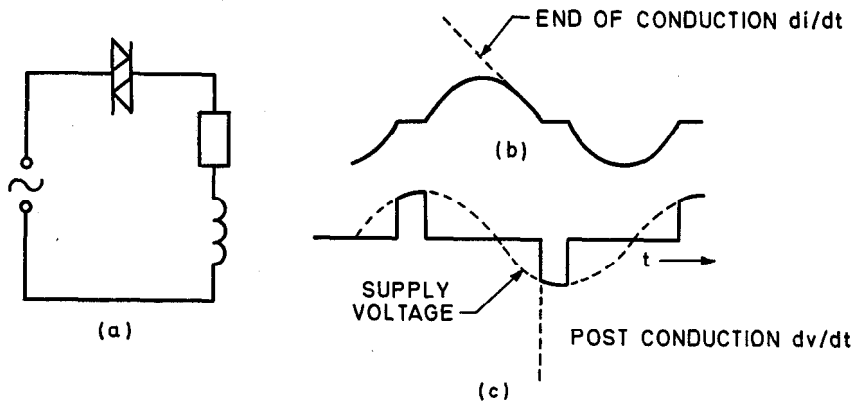


FIG. 8 TYPICAL EXAMPLE OF BIDIRECTIONAL THYRISTOR WAVE SHAPES IN AC REGULATOR WITH AN INDUCTIVE LOAD

9.4 The permissible post conduction dv/dt is quoted as a figure distinct from and usually lower than that which is applicable after an indefinite blocking period, and should be read in relation to a particular maximum rate of decay on-state current, the end-of-conduction di/dt . A suppression circuit is commonly necessary to limit the dv/dt , and the losses due to this, coupled with the restriction on end-of-conduction di/dt , tend to impose an upper limit on possible operating frequency.

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